AU/ACSC/GRELK/AY09

AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

NUCLEAR-POWERED AIRCRAFT

Potential Air Force's Future Alternative Fuel Persistence and Reach Platform or Crazy Idea?

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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Maxwell Air Force Base, Alabama

March 2009

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
APR 2009	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
NUCLEAR-POWERED AIRCRAFT Potential Air Forces Future Alternative Fuel Persistence and Reach Platform or Crazy Idea?	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Command And Staff College Air University Maxwell Air Force Base, Alabama**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The potential for a nuclear-powered aircraft to provide global persistence and reach, measured in months while consuming no petroleum fuel, seems alluring and worthy of pursuit. However operating requirements for such an aircraft, in addition to established political hurdles after Three-Mile Island and Chernobyl accidents, will limit the scope of a nuclear-powered aircraft program, if not eliminate the idea completely. By analyzing the potential uses of nuclear-powered aircraft against the legal requirements, the USAF can narrow its limited research and development investments in manpower and materiel to those technologies with the greatest opportunity for employment. This paper assumes a future security environment requiring attributes such as global range, persistence combined with ever rising fuel costs due to fuel scarcity. By analyzing the benefits of a nuclear powered aircraft in various roles against established nuclear legal principles, one can envision a concept of operations that allows future decision makers to effectively balance these risks while employing a nuclear-powered aircraft. Specifically, the aircraft would take off and land either on friendly airbases or international waters. It could then perform its mission over international waters then land at friendly air bases or sea ports. The only role examined that such an aircraft could not perform is attack because of the high likelihood of a nuclear-powered plane getting shot down, thus releasing nuclear radiation, would violate international conventions on the use of nuclear power. However, in the roles of ISR, cargo and missile defense, it could operate much like the nuclear navy operates today. Thus, while there would be limited utility for a nuclear powered aircraft today, this may not always be the case. The earths petroleum reserves will deplete eventually. If the USAF wishes to retain the military advantages that aircraft provide today, it must consider this reality and find alternative sources to power its future aircraft. While nuclear powered aircraft cannot be the panacea of capability to replace the aircraft the USAF uses in its various roles today, this research shows that it can be an alternative capability for rapid transport, ISR and missile defense in the future. Thus, the USAF should continue to examine the utility of such a capability in various future scenarios and monitor industry and military advances in light-weight reactor development that could, one day, be converted into a power source for a nuclear-powered aircraft.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**38**	

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Contents

Page

Preface

When I saw the topic of nuclear-powered aircraft on the list of topics to research at Air Command and Staff College, I was immediately drawn to it. In the course of my studies for my B.S. in nuclear engineering many years ago, I learned about the atomic nuclear plane and its enormous cost. My initial plan was to take on this topic and save the Air Force countless millions of dollars by creating a report that definitively showed that there was no possible way to successfully employ such an aircraft; thus convincing the Air Force to drop the idea all together as soon as possible. However, my hopes of finding the final nail in the coffin of a nuclear-powered aircraft were quickly dashed as I talked to instructors and subject matter experts that challenged my initial assumptions and provided insights on nuclear navy operations. The resulting journey resulted in changing my view from pessimist to advocate to one of "perhaps."

I would like to thank those who have been with me on this journey. Specifically, I would like to thank Lt Col Mathews for providing the encouragement to take on this topic, even when I discovered that finding supporting material would be a challenge. I also wish to thank LCDR Link for his insight and guidance for understanding the nuclear naval program and Mr. Rich Ouellette for his knowledge, insight and passion of nuclear-powered aircraft. Finally, I wish thank my wife, Mary, for her tremendous support and understanding of the time away from the family to research this topic and write the paper.

Abstract

The potential for a nuclear-powered aircraft to provide global persistence and reach, measured in months while consuming no petroleum fuel, seems alluring and worthy of pursuit. However operating requirements for such an aircraft, in addition to established political hurdles after Three-Mile Island and Chernobyl accidents, will limit the scope of a nuclear-powered aircraft program, if not eliminate the idea completely. By analyzing the potential uses of nuclear-powered aircraft against the legal requirements, the USAF can narrow its limited research and development investments in manpower and materiel to those technologies with the greatest opportunity for employment.

This paper assumes a future security environment requiring attributes such as global range, persistence combined with ever rising fuel costs due to fuel scarcity. By analyzing the benefits of a nuclear powered aircraft in various roles against established nuclear legal principles, one can envision a concept of operations that allows future decision makers to effectively balance these risks while employing a nuclear-powered aircraft. Specifically, the aircraft would take off and land either on friendly airbases or international waters. It could then perform its mission over international waters then land at friendly air bases or sea ports. The only role examined that such an aircraft could not perform is attack because of the high likelihood of a nuclear-powered plane getting shot down, thus releasing nuclear radiation, would violate international conventions on the use of nuclear power. However, in the roles of ISR, cargo and missile defense, it could operate much like the nuclear navy operates today.

Thus, while there would be limited utility for a nuclear powered aircraft today, this may not always be the case. The earth's petroleum reserves will deplete eventually. If the USAF wishes to retain the military advantages that aircraft provide today, it must consider this reality and find alternative sources to power its future aircraft. While nuclear powered aircraft cannot be the panacea of capability to replace the aircraft the USAF uses in its various roles today, this research shows that it can be an alternative capability for rapid transport, ISR and missile defense in the future. Thus, the USAF should continue to examine the utility of such a capability in various future scenarios and monitor industry and military advances in light-weight reactor development that could, one day, be converted into a power source for a nuclear-powered aircraft.

Part 1
Introduction

The potential of nuclear-powered aircraft to provide global persistence and reach, measured in days and weeks, while consuming no petroleum fuel seems alluring and worthy of pursuit. Especially in a world with finite supplies of the petroleum used to fuel aircraft today. However the legal requirements for developing and operating such an aircraft, combined with established political hurdles and associated public fears with nuclear power after the Three Mile Island and Chernobyl accidents, will limit the scope of any nuclear-powered aircraft program. An analysis of the potential uses of nuclear-powered aircraft against established nuclear and international airspace laws, will help the United States Air Force (USAF) focus limited research and development investments to technologies with the greatest potential for future employment. The following sections will explain why the USAF should consider developing nuclear-powered aircraft in the future, why the USAF has the legal authority to consider developing nuclear-powered aircraft and describe the method used to develop a potential operational concept that can be employed in the future.

Why Should the USAF Consider Nuclear-powered Aircraft?

The US defense strategy requires both global range and persistence in intelligence collection and power projection.[1] Currently, most of the USAF capabilities to collect intelligence and project power via aircraft rely exclusively on petroleum-based fuels that will eventually deplete. Furthermore, the US imports most of the petroleum resources from unstable regions such as the Persian Gulf, Venezuela, Russia and Nigeria. Thus US security depends upon current and potential future enemies. President Bush echoed this fact as he signed the 2007 Energy Independence and Security Act, by saying, American dependence on oil “threatens our

national security by making us vulnerable to hostile regimes in unstable regions of the world. It makes us vulnerable to terrorists who might attack oil infrastructure."[2]

The USAF must find alternatives to fuel its aircraft of the future. One alternative is nuclear power. The idea is not new. In fact, between 1946 and 1961, the USAF and the Atomic Energy Commission spent over $7 billion trying to build a nuclear-powered aircraft.[3] While no airplane flew under its own nuclear power, experiments showed the concept is possible. In 1955 General Electric modified a B-47 jet engine for a nuclear heat source. The engine was designated the X-39 and it showed, in ground testing, it could theoretically sustain a flight at 460 miles per hour for about 30,000 miles.[4] However, there was no associated air frame ever built and shielding was inadequate, ultimately contaminating 1,500 acres on the test site.[5] In a separate experiment the USAF converted a B-36 bomber, known as the Nuclear Test Aircraft (NTA), which carried an operating nuclear reactor 47 times from 1955 to 1957. While the reactor did not power the airplane, the experiment demonstrated a reactor could fly.[6]

While the ground tests of the X-39 engine and the flight tests results of the NTA were impressive, their development was too slow and at too high a price due to lack of direction. "The Aircraft Nuclear Propulsion (ANP) program was characterized by frequent changes in emphasis and objectives, varying from a research and development program to an accelerated program to develop a weapon system for the Air Force."[7] Without a set of goals, the project managers could not decide what research to support. This caused a great deal of waste. A US government study "disclosed various instances where it appeared that the Department of Defense did not furnish sufficient and timely guidance to those responsible for carrying out the ANP program."[8] The fatal flaw was that a small, light, high-powered and adequately shielded reactor had not been developed, yet the USAF was modifying an aircraft to carry such a system once developed as a

completely separate effort. In retrospect, the USAF should never have designed an airframe until it developed a suitable reactor.[9] These findings, along with advances in air refueling, Intercontinental Ballistic Missiles and the public concern about the dangers of flying a nuclear reactor, made the concept irrelevant.

The concept continues to be irrelevant as long as petroleum-based fuels are readily available and nuclear power generation is feared by the public. However, this may not always be the case. Both the nuclear industry and the aircraft industry had nearly 50 years of technological advances to support developing a nuclear-powered aircraft. In the aerospace industry, materials technology created stronger, lighter materials to build airframes and provide advanced shielding. Additionally, aircraft can fly around the world via remote control, thus significantly reducing the shielding requirements during operations since an air crew may no longer be necessary.

Similarly, the nuclear industry had several significant breakthroughs in lightweight reactors development. In fact, an international design effort made up of nine countries and 18 industry, laboratory and university organizations has a scalable reactor design in the Nuclear Regulatory Commission approval process with hopes of earning final design approval in 2013 and deployment as early as 2015.[10] Last year a USAF Fellows student researched portable nuclear energy system concepts that could be developed by 2020 and highlighted three concepts weighing between 1.25 – 40 tons with power outputs ranging between 40 – 200 Megawatt hours with lifetimes ranging between 10 and 84 months.[11]

While these advancements address the technological problems of 1960, President Kennedy cancelled the ANP program because missiles could provide global reach and air refueling could provide airplanes both the reach and persistence necessary to keep nuclear weapons in the air or on alert 24/7 and transfer materiel rapidly around the globe.[12] What has

changed in the military environment the past 50 years to warrant another look? First, the availability of tankers to continuously supply fuel is finite. As oil reserves fall and prices rise, the USAF will either spend ever-increasing amounts to continue using its aircraft, limit its combat capability or provide another fuel alternative. Second, the size of Air Force personnel and equipment continues to shrink. If an aircraft could simply fly to a given airspace and maintain its presence for days at a time, then the number of aircraft required to provide 24/7 coverage drops significantly. Subsequently, the resources required to maintain and sustain such a fleet of aircraft are reduced as well.

Can the USAF Legally Consider Nuclear-powered Aircraft?

Nuclear power poses unique risks to the health and safety to both people and the environment. These risks must be carefully managed and avoided when possible. However, nuclear power also promises many significant benefits in a variety of current and future military applications. These benefits range from nuclear-powered ships and submarines the Navy uses now to providing power to military installations in the United States and austere locations in the future. Human activity that involves only hazards and no benefits calls for a legal regime of prohibition, not regulation; thus a basic feature of nuclear power legislation is its dual focus on risks and benefits.[13] Any proposed new application of nuclear power must strike a balance of having benefits that outweigh potential risks of its employment.

Today, the risks associated with developing and operating nuclear-powered aircraft would outweigh any potential gain as petroleum fuel is readily available. However, this will not always be the case and the US must look at all the available alternatives as it plans for its future against a wide range of potential scenarios. As the USAF examines possible alternatives, all ideas should be examined thoroughly, and not easily dismissed, to ensure a potential viable

option remains part of the analysis. A nuclear-powered aircraft option could be quickly dismissed by decision makers thinking it would not be possible to develop such an aircraft or that political will would never allow such technology to develop. However, technological advances can make seemingly impossible ideas come to life and political will is a variable that changes with time. Thus, the USAF should explore the potential employment of a nuclear-powered aircraft in the future in the event it becomes vital to national security interests.

The Atomic Energy Act of 1954 (as amended) states the Commission, later amended to the Department of Energy, may "conduct experiments and do research and development work in the military application of atomic energy."[14] Thus the law clearly allows for future experimentation and concept development of such an aircraft. Not surprisingly, the law would have to be amended to successfully field such technology because it only provides authority to process and transport waste created by naval nuclear propulsion programs. However, if ever there was a future political environment where the benefits of a nuclear-powered aircraft outweigh the risks of its employment, an amendment could be added to the legislation. Hence, nuclear-powered aircraft in future scenarios can be considered in future scenario analysis. The Air Force could develop such a capability in the interest of national security. Whether nuclear-powered aircraft should be developed is bigger discussion not explored in detail by this paper.

Rather, this research examines whether the legal requirements for one of the proposed solutions, nuclear-powered aircraft, effectively eliminate it from consideration or shapes the ways and means it operates. Specifically this research focuses on the legal principals, vice the technological aspects, because the USAF has demonstrated nuclear-powered propulsion is possible. Fifty years of advances in both the nuclear and aerospace industries increase the

likelihood of developing a nuclear-powered aircraft and enhanced the safety of such a machine if the USAF pursues such capability.

Thus, the issue is not whether the AF can fly a nuclear-powered aircraft, but whether it has the political will to do so. While there is no will to pursue such technology now, the likelihood of political will changing increases as oil prices skyrocket as reserves deplete. When that happens, the US must choose how it will limit its defense or provide another way to fuel its military might. This research can guide USAF investment in potential uses of a nuclear-powered aircraft to maximize the potential for successful employment in future scenarios.

Part 2

Examining International Nuclear Law and Principals

The International Atomic Energy Agency's (IAEA's) Handbook on Nuclear Law defines nuclear law as:

> "The body of special legal norms created to regulate the conduct of legal or natural persons engaged in activities related to fissionable materials, ionizing radiation and exposure to natural sources of radiation."[15]

The handbook further explains the definition is comprised of four key elements. These are:

1. Nuclear law is recognized as part of a general national legislation,
2. The regulation incorporates the risk-benefit approach to manage activities that present hazards and advantages for social and economic development,
3. The regulation relates to the conduct of legal persons to include commercial, academic, scientific and governmental entities
4. Radioactivity as the defining feature justifying a special legal regime.

This research focuses on the risk-benefit approach element because developing a nuclear-powered aircraft is a new application of nuclear power use by the US that has a well established military and civilian nuclear enterprise with legislation and institutions regulating its use and development. Specifically, this risk-benefit analysis focuses on the applicable principles of nuclear law that distinguish the use of nuclear activities, in this case developing and operating a nuclear-powered aircraft, from other aspects of national laws. The nuclear principals are safety, security, responsibility, permission, continuous control, compensation, sustainable development, compliance, independence and transparency.[16]

This paper focuses on the safety, security, compensation and compliance principals as they are the key principles drive the risk-benefit considerations of a nuclear-powered aircraft. For each principle this paper provides the definition as provided by the IAEA Handbook on Nuclear Law and explains why it would apply to a nuclear-powered aircraft concept analysis.

The other principles either do not apply to military uses or center on a state's legal requirements for starting and running an independent nuclear energy industry. In essence the responsibility, independence, permission and control principles state there must be a single organization responsible for ensuring safe and secure use of nuclear material. Furthermore that organization must be independent of the organization promoting development and use. Additionally the regulator must have continuous ability to monitor use to ensure all activities are authorized. These principles apply to all nuclear reactor operations and would not be distinguishing factors for analyzing concepts of nuclear-powered aircraft. Finally, the transparency principle applies to peaceful nuclear use and does not apply to military programs.[17]

Safety Principle

The potential for great harm to both persons and the environment through the misuse, abuse and unintended accidents can be very significant. A nuclear accident can not only create devastating blast effects, but can also release harmful radiation into the air and ground that can sicken and kill all forms of life for generations. As a result, there are many national laws, internal instruments, regulatory documents and expert commentaries that emphasize that safety is "the primary requisite for use of nuclear energy."[18]

When it comes to safety there are three subsidiary principles articulated in nuclear law. These are the prevention, protection and precautionary principles. The 'prevention principle' states the primary objective of nuclear law is the use of both caution and foresight to prevent damage caused by the application of nuclear technology and minimize any adverse effects resulting from either misuse or from accidents. The 'protection principle' states the fundamental purpose of regulation balances social risks and benefits. "Where the risks associated with an activity are found to outweigh the benefits, priority must be given to protecting public health,

safety, security and the environment."[19] Finally the 'precautionary' principle states in cases where the balance cannot be achieved, the rule of nuclear law requires protection. Specifically this principle requires the user to understand it has the responsibility of preventing foreseeable harm.

Clearly the safety principle must be the primary focus on any planned development and employment of a nuclear-powered aircraft. While the US has successfully operated nuclear reactors throughout the country and sails them throughout the world in nuclear submarines and ships, a nuclear-powered aircraft would pose a unique safety concern. Such an application would add a whole new dimension to the "not in my backyard" syndrome when a future accident could be in populated areas. Such close proximity to a nuclear core would be even more devastating than an accident from a power reactor that is purposefully built a safe distance from population centers to minimize damage in the event of an accident.

Perhaps even more important than the true risk to the population would be the perceived risk to safety by the public. The Three Mile Island catastrophe left a lasting impression of nuclear power. In fact, no new nuclear power reactors have opened since the accident. The public disapproval is centered around nuclear power plants that are firmly planted on the ground. Imagine the type of benefits a nuclear-powered plane must provide to successfully counter this perceived risk to the public. Thus, changing the perception of nuclear power, its safety and benefits will have to be the driving factor for any concept of operations of such an aircraft.

Security Principle

Similar to the safety principle, the misuse of nuclear technology can pose health and safety risks, as well as risks to the safety of individuals or institutions, if diverted to malicious actors. Lost, abandoned and stolen radiation sources can cause injury to individuals unaware of

the associated hazards of uncontrolled radiation. Furthermore, terrorist or criminal groups with radioactive sources can potentially produce radiation dispersion devices to commit malevolent acts.[20] Thus special security measures must be in place to protect and account for the types and quantities of nuclear material that can pose security risk. These measures must protect against diversion while allowing legitimate use of such materials and technologies.

Current security laws are written with the assumption that the reactor is either on land or a US Navy ship or submarine. Reactors on land are surrounded by barriers and surveillance and have several layers of security to limit access to the most critical components of the reactor. Likewise, US Navy ships and submarines have similar protection measures, but with the added advantage of being protected by the finest navy the world has known. In the event of a catastrophic accident where a ship is lost, the US Navy can quickly secure the suspected area. Thus, if the nuclear material was retrievable, the US Navy would be the lone actor available to recover it and ensure security. In short, there is a very low probability that unauthorized individuals could remove radioactive material from these reactors.

A nuclear-powered airplane could have security measures similar to the Navy's when it is on the ground or flying over sea. However, it cannot have these security measures while flying over land. The security risk would be further exacerbated if the wreckage was never found, which could happen if flying over foreign soil. The risk would then be a belligerent state or organization could find the material and use it for a dirty radioactive weapon.

Compliance Principle

Generating nuclear power is not the only human activity that can cause damage to humans and the environment outside a state's borders. However, international nuclear law requires the territory of a state must not be used in such a way as to cause damage in another

state and that control measures are necessary to prevent such damage.[21] Thus even if damage from a nuclear accident does not fall on the guilty states' boarders, it is still liable for the damage it caused.

This principle greatly limits nuclear-powered aircraft operations. It basically discourages a nuclear-powered aircraft from flying over a country that does not want it. The control measure for preventing a nuclear-powered aircraft from causing damage to another state is simply turning it around. Of course in war adherence to international convention is not a factor, in that states attack one another and cause damage across state borders intentionally. However, such aggressive use of a perceived threat would certainly have ramifications that shape a concept of operation in such a wartime scenario.

To illustrate just how heavy the international pressures can be to comply with international conventions, in 1978 the Soviets intentionally de-orbited a nuclear-powered satellite. The result was a release of nuclear waste over a significant portion of Canada. After considerable duress from international pressure the Soviets eventually paid for all damages.[22] The fact they spent the resources at a time their economy was under complete collapse is a testament to just how heavy the political pressure can be to the compliance principle.[23]

Compensation Principle

By its very nature, nuclear energy risks major damage to persons, property and the environment. No amount of preventive measures can mitigate the potential for such damage. Thus, nuclear law requires that States adapt measures to provide adequate compensation in the event of a nuclear accident.[24]

The compensation principle provides the penalty for failing to correctly balance the risk versus benefit in the use of a nuclear-powered airplane. Simply put, if nuclear-powered aircraft

causes damage to the environment or humans, the US government will have to fairly compensate the affected individuals and restore the environment. This can be incredibly expensive and time consuming. To give an idea of just how significant this compensation price tag could be, the cleanup cost for the Three Mile Island disaster was over 975 million dollars over 14 years.[25]

This principle applies not only to US territory, but to anywhere in the world where the airplane, under the control of the US, could cause an accident. The combination of the compliance and compensation principles was so important for the Navy to access ports that it was codified into Public law 93-513 which states the US "will pay claims or judgments for bodily injury, death or damage to or loss of real or personal property proven to have resulted from a nuclear incident involving the nuclear reactor of a United States warship."[26] Thus, it is logical to have such liability extended to damage caused by a nuclear-powered aircraft.

Analysis of Current US Nuclear Law Regarding the Principles

The US has a well established legal history as it pertains to the principles of nuclear law. The Atomic Energy acts of 1946 and 1954 created the Atomic Energy Commission which was solely responsible for both the development and production of nuclear weapons and developing and regulating the civilian uses of nuclear materials. This far reaching legislation covers all aspects of the legal principles outlined by the IAEA. However, for the purpose of this research, Sections 29, 57 and 170 contain the legal guidance for the safety, security and compensation and compliance principles.

The Energy Reorganization Act of 1974 abolished the Atomic Energy Commission and split the responsibilities between two independent organizations.[27] The Department of Energy was assigned the responsibility for developing and producing nuclear weapons and promoting nuclear power. The Nuclear Regulatory Commission was assigned responsibility for regulating

civilian uses of nuclear material. The Nuclear Regulatory Commission has since delegated much of its responsibilities to the States where nuclear facilities reside.[28]

The Air Force divides management responsibilities between the Air Force's Radioisotope Committee (RIC) and the Air Force Safety Center. Like the Department of Energy, the Air Force Safety Center, oversees the use of Atomic Energy Act Section 91(b) material (e.g. nuclear weapons systems, certain radioactive parts of nuclear weapons systems, military nuclear reactor systems, certain parts and fuel for such systems). These responsibilities are provided in AFI 40-201, and AFI 91-109 regarding nuclear reactors, and AFI 91-101 regarding the AF nuclear weapons surety program.[29]

Likewise, similar to the Nuclear Regulatory Commission's responsibilities, the RIC oversees the use of all radioactive materials within the Air Force except for that material which falls within the scope of Atomic Energy Act Section 91(b). These responsibilities are also described in AFI 40-201. Furthermore, the RIC serves as the single point of contact for the Air Force with the Nuclear Regulatory Commission. As the USAF point of contact to the Nuclear Regulatory Commission, the RIC holds and administers a Master Materials License, issued by the Nuclear Regulatory Commission under the Atomic Energy Act to regulate the acquisition of, use, possession, management, transfer, etc. of source, special nuclear, and byproduct material. The RIC administers the license in part by issuing permits to AF organizations to possess, use, etc. radioactive materials.[30]

The fact the US has successfully operated nuclear power plants and has an active nuclear infrastructure is evidence of its success in adhering to all the principles of nuclear law. Furthermore, the fact that the United States' Navy possesses a world-wide fleet of nuclear-powered ships and submarines and the USAF possesses and maintains nuclear weapons is

evidence the Department of Defense has a firm grasp of nuclear law. Granted, the USAF had to have a series of embarrassing incidents to regain its focus, but there is no doubt it is back on track. Thus, methods of employing a nuclear navy and USAF nuclear weapons can provide a useful template from which to build a nuclear-powered aircraft concept.

While the US and the military may have a firm grasp of nuclear law, it does not mean there have been no accidents that lead to injury and death. In fact, there have been some very public and incredibly dangerous events such as the Three Mile Island scare. Such accidents have occurred in the military as well. In a report detailing military nuclear accidents authors Jay Tiwari and Cleve Gray document 48 accidents involving nuclear weapons and nuclear-powered submarines. The most severe cases involved errant nuclear-tipped missiles landing in the ocean, radiation contamination on United States and foreign soil and the loss of a nuclear-powered submarine and its nuclear weapons in the sea.[31] However, the fact that the United States has been able to successfully manage such situations and still remain as a respected nuclear power only strengthens the argument the US stands of a firm legal foundation.

Legal principles do not mandate zero risk. Rather, much of the international community recognizes that safety and security risks must be balanced against the benefits possible from using nuclear material. Additionally, the compliance and compensation principles provide a quantifiable resource to judge whether a state can accept the risk, i.e., whether it can afford the consequences of cleaning up an accident from its use. Thus, key to whether the USAF should develop and operate a nuclear-powered aircraft depends greatly on how it would be employed.

Part 3

Nuclear-powered Aircraft Employment Considerations

Part two provided the foundation of understanding of the legal principles and US law surrounding nuclear energy and its use. This part provides the foundation of the application of air power and how a nuclear-powered aircraft can provide utility. It explores how nuclear energy can support air power as well as the legal basis of the application of air power in various roles.

Key Assumptions

This analysis uses three key assumptions necessary to consider nuclear-powered aircraft operations in future scenarios. First, this analysis assumes an environment where no alternate fuel exists to adequately replace petroleum-based fuels used by the USAF to power its legacy aircraft. Second, this analysis assumes the US decides the benefits gained from nuclear-powered aircraft are worth the risks associated with its development and employment. Finally, this analysis assumes the USAF will place operational constrains on nuclear-powered aircraft use to ensure the safety and security of people and the environment. The following paragraphs provide the necessary details of these assumptions.

The first assumption examined is the lack of fuel alternatives in the future. This assumption is necessary because currently the United States does not require a nuclear-powered aircraft. Petroleum-based fuels provide the energy necessary to maintain and operate an air force capable of projecting power anywhere in the world right now. However, the world's petroleum resources are finite and will eventually run out. As petroleum becomes scarce, the price of maintaining a fleet of petroleum based aircraft will rise exponentially. This will force the United States to either develop an alternative energy source to fuel its Air Force, pay ever increasing amounts for the limited fuel, or abandon its ideology of projecting power from airplanes.

The second assumption is the US determines benefits gained are worth the safety and security risk assumption. This assumption is just as critical as the first. The only way to discuss how a nuclear-powered aircraft could be employed is to assume the painstaking decision to develop such an aircraft was made by the US through its legal process. In so doing, this paper assumes the US would amend the Energy Reorganization Act, Sec 90 to include nuclear-powered aircraft along with the wording of the nuclear naval fleet. Additionally, this paper assumes PL 93-513 would also be amended to include US liability at any airfield or port a nuclear-powered aircraft would land, in addition to covering the liability from an accident on a nuclear-powered ship.

While no one can predict the set of conditions that would lead the United States to make such a decision, it certainly is possible. The likelihood of employing nuclear-powered aircraft is possible if there is no other suitable alternative fuel and the United States relies on nuclear power to fuel its energy needs in the future. In such a scenario public confidence in nuclear power could increase dramatically, relative to today, and the fear of nuclear power use would decrease. Such a scenario also provides the Air Force with a core group of talent within the population to draw from and operate nuclear-powered aircraft. Thus, whether or not the United States can find itself in a situation where a nuclear-powered aircraft is acceptable is very dependent upon the conditions provided in any given scenario.

Finally this analysis assumes the initial employment of any nuclear-powered aircraft would be limited to the immediate shoreline of the United States and over international waters, thus modeling the employment of the nuclear navy. This restraint could diminish over time as confidence in the technology improves through demonstrated performance. This limitation is necessary to ensure the safety of people and the environment on land as well as ensure security

of any nuclear material released in the event of an accident. While an accident over the ocean would cause damage in the immediate area of the accident, damage would be minimal and threat of prolonged exposure to either human or animal would be limited because it would rest on the bottom of the sea bed. Furthermore, the ocean provides security of the nuclear material from a terrorist organization or rogue nation. At the bottom of the ocean floor, the material could only be accessible by nations with sufficient capability to reach the wreckage, let alone recover it.

Of course, not all would agree such a scenario is an acceptable risk as there is life, even on the ocean floor, that would be disturbed by a nuclear accident. However, ditching a nuclear-powered aircraft into the ocean would only be used as a final resort. While such an accident would be a significant environmental event, it is a risk the United States is willing to take, even today. There are nuclear-powered submarines and ships operating worldwide by the United States Navy. Furthermore, the United States Air Force transports nuclear weapons and other hazardous cargo. Accidents aboard both ships and planes can and have occurred that impacted the environment. In fact, the Navy has lost a nuclear-powered submarine[32] and there are approved procedures for crews to ditch their hazardous cargo into international waters if necessary.[33] Thus, if it is a risk worth taking now, it is logical to assume that in the future, the US would be willing to risk placing nuclear material into international waters in the event of a catastrophe on a nuclear-powered aircraft.

Aircraft Type

The operational limitations described would not eliminate the utility of a nuclear-powered aircraft. In fact, many of the limitations apply to military aircraft today, depending on how it is employed. The following paragraphs describe the potential roles and security benefits a nuclear-powered aircraft provides to the US.

Attack aircraft provide the capability to rapidly project both nuclear and conventional power to any location at any time in any weather. This power can support ground forces in direct combat, prevent enemy reserves from entering the battle or disrupting strategic targets such as enemy leadership, communications nodes or industries used to develop future combat forces. These are critical capabilities currently used by Combatant Commanders and would certainly benefit the US in any future conflict where it would be the only state able to present such capability through nuclear-powered aircraft. In essence it would be the equivalent of achieving air superiority over an adversary without attacking it! US forces would be free from attack from the air, while enjoying the ability to attack from the air; not because the adversary's air powers were destroyed by the USAF, as they are today, but via the fact the enemy cannot fuel its aircraft. Furthermore, in addition to providing the capability to simply be airborne to threaten and attack an enemy, nuclear-powered aircraft would not require frequent refueling required by conventional aircraft. This provides a persistent threat of attack over a large area using a single aircraft for time periods not possible today. Such an advantage cannot be quickly set aside.

However, while an enemy's offensive capability to employ air power diminishes when petroleum depletes, its ability to defend itself does not. Enemy air defenses rely on chemically powered missiles and artillery in addition to aircraft. Thus, while enemy air forces cannot defend against air power, missiles and artillery shells can shoot down aircraft. The principles of nuclear law, specifically safety, demand this unavoidable reality be explored in depth.

Just as attack aircraft can project conventional and nuclear effects to an enemy anywhere in the world, cargo/ferry aircraft can project support to forces or populations anywhere in the world. The support can be humanitarian, as it was in the Berlin airlift, or it can be force projection as it was in the air drops of infantry personnel and supplies onto Normandy in World

War II. In an environment where air power is not available because of the lack of fuel to support it, the US would have to rely on ground transportation to move its supplies in a theater and naval power for projection outside of a land theater of operations.

Rapid support via air power would have immediate strategic effects in both humanitarian and military scenarios where the United States would be the only state capable of providing such support both at home and abroad. Imagine the Soviet blockade of Berlin without air power support or the rapid build-up of manpower and equipment for OPERATION DESERT SHIELD/STORM. In both cases aircraft rapidly supplied civilian and military commanders with the equipment necessary to be successful. In the case of the Berlin airlift, aircraft were the only means available to deliver the supplies. In the case of OPERATION DESERT SHIELD/ STORM, the rapid buildup of forces would have taken much longer. Such a capability in the future, when no other country is capable of doing so, due to a scarcity of fuel, would have tremendous positive strategic advantages in future scenarios.

Intelligence, Surveillance and Reconnaissance (ISR) aircraft provide critical information on air, land and sea based targets. In a scenario with no enemy air forces, such a capability can focus exclusively on land and sea based targets. More importantly, a single nuclear-powered aircraft could remain on site to collect data for very long periods. While it is currently possible to use batteries to fly miniature ISR unmanned air vehicles (UAVs) their use is limited to providing an overhead picture of the immediate battlefield. Satellites also provide tremendous information on the enemy but their ability to be on a particular area of interest is limited to its orbital paths. In the case of a persistent satellite in a geosynchronous orbit, it is very far away, thus limiting its target collection capability. Thus an air based collection platform can simultaneously provide both the persistence and flexibility of ISR collection currently enjoyed

by United States forces. Such a capability would be a tremendous advantage to future commanders; even more so than today because the lack of any air targets would allow operators to focus on ground targets.

The Airborne Laser (ABL) is designed to defend the United States from a limited missile attack either from a rogue nation or a terrorist group overthrowing a failed state in possession of such missiles. The projected ABL shield is superior to a missile shield based in the homeland because it destroys the missile in its boost phase, thus either sending the missile and warhead into the ocean or upon the hostile nation that intended to deliver its contents to the United States. This use is far superior to a missile based defense based in the homeland because while the missile may be destroyed before it reaches its target, the contents of the missile would fall upon the homeland, thus diminishing its usefulness. Such a capability is considered very important today and would likely remain a priority in the future.

Finally, a tow concept could prolong the use of petroleum based fuel aircraft in globally projecting US air power. In a tow concept of operations a nuclear-powered airplane would continuously fly back and forth across the ocean. As it left one coast, conventional aircraft, i.e., fighters/bombers/ISR/cargo would fly behind the nuclear-powered tow aircraft and then lock onto a probe, much like an air-to-air refueling operation. The conventional aircraft could then be towed across the ocean conserving its fuel for when it arrives to the theater of operation. Once the towed aircraft approaches its area of operation, it could detach and operate as it does today.

Another aspect of the tow concept combines the cargo tow concept explained above with an ISR platform. Thus rather than towing a cargo aircraft, the nuclear-powered aircraft could tow ISR platforms that simply use the nuclear-powered aircraft to pull it along as they fly over international waters or over lands that grant them access to fly overhead and collect information.

International Laws on Flying Aircraft

Employment of aircraft not only depends on its intention for use, but also on where it operates. By international convention, through the Chicago Treaty of 1944, the notion of a state's sovereign airspace matches with the maritime definition of territorial waters as being 12 nautical miles out from a nation's coastline and the land above its territory (not to include space). Thus, airspace not within any country's territorial limit is considered international, analogous to the "high seas" in maritime law.[34] As a result, aircraft must operate differently over sovereign airspace than they do over international waters. These differences are important when considering the role of a nuclear powered aircraft. How the USAF employs the aircraft will certainly play into a state's risk-benefit calculation whether to allow the aircraft to enter its airspace. The remaining paragraphs of this section explore these differences.

To fly over a sovereign state or within 12 miles of is coast line, if one exists, an aircraft must have permission of that state. Whether or not such permission is granted depends upon the relationship the state has with the US as well as the intended purpose of the flight.[35] For example, a state could deny over-flight rights to a military ISR aircraft but allow a military aircraft carrying humanitarian aid to enter its sovereign airspace.

The penalty of violating a state's airspace can be severe. The state has the right to shoot down an aircraft violating its airspace as when the Soviets shot down a USAF U-2 in 1961. Even in situations where the enemy lacks the capability to shoot down an aircraft, violations of a nation's airspace are viewed as an act of aggression that is unacceptable in international law. The affected states can provide its grievances to the international community to bring diplomatic pressure against the US to end the violations. Such pressure can be very effective because the US wants to be viewed as a nation accepting of international laws and a beacon of freedom.

The impact of not having over-flight rights can be severe and dramatically shape strategy for the United States. For example, in the campaign to overthrow the Saddam Hussein regime in 2003, the US was not able to secure over flight rights from Turkey. This dramatically changed the approach to OPERATION IRAQI FREEDOM.

Planes flying in international airspace over the seas are subject to the rules regarding air traffic control and the legal requirements of their respective countries. Specifically, USAF aircraft are subject to DODI 4540.01 *Use of International Airspace by U.S. Military Aircraft* and if they are carry hazardous cargo, Air Force Instruction 11-204, *Operational Procedures for Aircraft Carrying Hazardous Materials*. These documents provide specific procedures that ensure safe passage of cargo and passengers as well as any potentially affected parties where the plane will fly. Most importantly it provides guidance on what to do in cases of emergency, specifically if hazardous cargo must be jettisoned from an aircraft. This is very applicable to a nuclear-powered aircraft operations discussion because current US guidance allows aircraft, with proper authorization, to jettison hazardous cargo over international waters but not over land.[36]

Recognizing this fact is important because it provides insight where the US is willing to accept risk, such as international waters. More importantly, it highlights the US is unwilling to accept risk on land. This is key in creating an operational concept balancing gains of a nuclear-powered aircraft against risks. In fact, one does not need to look any further than the fact that US Navy carrier and submarine fleets are propelled by nuclear power. The US shows a willingness to risk damage to persons and the environment through its nuclear navy. It accepts this risk because the security benefits a nuclear-powered navy provides outweigh the risks associated with a nuclear accident. If a nuclear-powered aircraft could demonstrate benefits similar to a nuclear-powered navy in future scenarios, the US may accept its risk also.

Part 4

Analyzing Nuclear-Powered Aircraft Employment Against Nuclear Principles

When all the legal principles are considered against the backdrop of the employment limits and constraints of air power, three fundamental employment concepts emerge. The first would be a conventional take-off and landing from a shore-based airfield and the other would be from a sea-based plane that would take off and land from the sea. Finally, the third approach would be a combination of the two concepts, an amphibious plane that could take off and land from either land or the sea. The advantage of a conventional take-off and landing concept would be the ability to use existing airfields and their associated infrastructure. However, it would require the aircraft to fly over land and risk injury to anyone on the ground in the event of an accident. The advantage of a sea-based plane is it would never have to fly over land, thus greatly reducing the likelihood of contaminating a state and its citizens. The disadvantage is there is no USAF infrastructure to support a fleet of nuclear sea-based planes. However this limitation could be reduced if aircraft are compatible with the US Navy's nuclear infrastructure.

Thus, the best approach is an amphibious-based design. Such an approach offers the flexibility necessary for commanders to balance risks and benefits of operating a nuclear-powered aircraft. For example a nuclear-powered aircraft could take off from a US airbase, fly over international airspace to deliver cargo at a sea port or an ally's air field if granted such permission. Or, the aircraft could launch from a US sea port, perform its mission over international airspace and return to the sea port. An amphibious aircraft would also provide additional safety in an emergency because it could land rather than ditch into the ocean.

Thus, the recommended concept of a nuclear-powered aircraft consists of an amphibious aircraft taking off from either an air or sea base, flying over international airspace to perform an

attack, cargo/ferry/tow, missile defense or ISR mission and landing at either an air or sea base. Limiting over-flight to international waters maximizes the US ability to meet the nuclear legal principles of safety, security, compliance and compensation. The concept is safe and in that any nuclear material released in an accident would either be limited to the sea bed or on a military base, ultimately reducing the risk to the health of humans and the environment, and reducing the likelihood any nuclear material falling into undesirable individuals or groups. It meets the compliance principle in that the plane operates only in international airspace or within the airspace of countries that agree to allow it to fly. Finally, if the United States amends the law that accepts liability on nuclear-powered warship in foreign lands to nuclear-powered aircraft, then the compensation principle would be satisfied as well. The remainder of this section will apply this concept of employment to the various aircraft roles described earlier to determine whether future commanders could successfully employ nuclear powered aircraft.

Attack

There are limited benefits gained from employing a nuclear-powered attack aircraft that would not justify the increased risk to both humans and the environment. Simply put, the enemy would attempt to shoot down the aircraft. Even worse, due to the hazardous cargo associated with the aircraft, the enemy would have tremendous incentive to shoot the incoming aircraft well before breaching its boarder so the contents won't come onto its territory. The precautionary principle requires the United States to consider this outcome as it debates whether or not to employ a nuclear-powered attack aircraft.

Thus, if the United States attempts to attack using a nuclear-powered aircraft it would violate the four principles studied. It violates the safety principle because it invites retaliation for its use thus violating the precautionary subsidiary principle. The result of getting shot down or

having an accident over land will likely cause injury, death or illness to individuals that did not receive any benefit of its use. It violates the security principle because, in the event of an accident or getting shot down, the material is not only out of the control of authorized operators from the United States, it is in the control of individuals with incentive to use it in a retaliatory manner that will be harmful to more people. It violates the compliance principle because its use has transcended its consequences beyond US boarders. The compliance principle requires states to use control measures to prevent releasing materials onto other states or to threaten other states with nuclear material release. With nuclear-powered aircraft the control measure would be flying over international airspace. Finally, the compensation principle would generate international demands for the US to pay for the damages, much like the demand for the Soviet Union to pay for the cleanup from its nuclear-powered satellite that crashed onto Canada.

Thus, for the foreseeable future, it would appear that the only type of scenario the US should risk employing a nuclear-powered aircraft would be when attacking targets of an enemy that cannot present an air defense and can be reached by weapons employed from international airspace. Even in situations where such a country existed, there is no benefit to striking it via a nuclear-powered aircraft because naval forces using cruise missiles can provide the same combat effects. Furthermore, the US could find more efficient methods of employing weapons high enough in the air to fire upon an enemy from in international waters i.e., cruise missiles dropped from a solar powered dirigible. While these capabilities would not be cheap, they would be far more efficient than the dollars necessary to develop and operate a nuclear-powered aircraft.

Cargo/Ferry, ISR and Missile Defense

Cargo/Ferry, ISR and Missile Defense missions can be analyzed together as a group because, unlike attack aircraft, they will not operate in an environment where likelihood of

getting shot down is high. While there can be exceptions, for the most part aircraft flying such missions do so only when air superiority or dominance is available. As such, the nuclear principles could allow effective employment of nuclear-powered aircraft to perform cargo/ferry, ISR and missile defense missions. First, the USAF could operate cargo/ferry, ISR and missile defense aircraft strictly over international air space with the employment concept proposed. In fact, the concept for such missions is the similar today. Second, balancing benefits against safety risk calculations change depending upon its role and where it is employed. The difference in this case is the "targeted" country gets to balance the benefits versus the potential risks.

For example if the aircraft is rapidly providing humanitarian relief after a catastrophe, the likelihood of acceptance is greater than if the aircraft is supply military might in the form of combat troops. In the humanitarian example the US could possibly achieve over-flight and landing rights so the relief could be provided as close to those affected as possible. As with any flight, there is always a risk of an accident. However, if the disaster is so significant that relief provided by a nuclear-powered aircraft is worth the risks associated with the flight, the host nation has the right to choose whether or not it wants the relief.

Of course, benefits of nuclear-powered cargo aircraft would not be limited to humanitarian missions. Cargo, ISR and missile defense missions in the air can have game changing effects and need to be explored in war game scenarios. The key difference between employment of a cargo, ISR and missile defense aircraft in international and friendly skies and employment an attack aircraft is the "targeted" state is allowed to make the risk versus benefit determination for itself, rather than the United States coercing the state. This distinction can have strategic impacts to international perceptions of the US as a lone superpower. In the case of ISR, cargo and missile defense the US projection of power could be viewed as beneficial to

international security environment vice being viewed as an international bully in the case of using attack aircraft in an environment where no other state can do the same

Tow

Finally, the tow concept is analyzed separately because of its unique employment concept that combines use of both nuclear-powered airplanes and traditional aircraft. Like the other aircraft, with the exception of the attack role, the tow concept does follow the nuclear principles examined in this analysis. However, it does not seem likely there would be a scenario where the benefits of creating a nuclear-powered aircraft would outweigh the safety and security risks associated with its operation when petroleum fuel is still readily available. The only way such a program could convince future lawmakers to make such an investment when conventional air craft could be used (albeit very expensively) is if the tow plane was sold as a proof of concept that could extend the useful life of conventional aircraft. The knowledge gained from the proof of concept aircraft could then advance development of nuclear-powered aircraft in the roles previously examined.

Part 5

Conclusions and Recommendations

The concept of a nuclear-powered aircraft is not just a crazy idea. A scenario where benefits gained by a nuclear-powered aircraft can overcome the risks from its use is possible. However, nuclear-powered aircraft would not be a panacea of capability provided by petroleum-based aircraft operated by the USAF today. Employment of nuclear-powered aircraft would be limited to ensure the USAF operated within the guidelines of the principles of safety, security, compliance and compensation. Part 4 demonstrated these principles are met when the USAF utilizes a concept of operations where an amphibious nuclear-powered aircraft takes off from a US coastal base or sea port, operates over international and friendly airspace, and then lands at either a coastal airbase or sea port. Finally, employment concepts would be limited to supporting and defense roles such as ISR, transport and missile defense missions.

This research opines that nuclear-powered aircraft should not be used as an offensive attack platform. Using nuclear-powered aircraft in such an aggressive manner encourages threatened states to shoot down the aircraft as far away from its homeland as possible. If a counterattack was successful and the aircraft fell on a neighbor, the US would likely be liable for any damage when the US is the aggressor and the targeted state was defending itself. Even if the US used a nuclear-powered aircraft to prevent an attack, it may still be held liable for damages because it could use cruise missiles launched from sea or land. Furthermore, the anti-aircraft missile threat would force weapons launch from international waters and letting the weapon fly or glide to its intended target. Such tactics from a nuclear-powered aircraft are not necessary because a nuclear-powered ship or submarine can perform the same function.

This research further shows the US should limit nuclear-powered aircraft employment to scenarios where the affected states' leaders make the risk versus benefit decision on its employment; not US leaders. In scenarios where the state chooses not to benefit from nuclear-powered aircraft benefits, the US must limit its use to international waters because the oceans provide the only chance for safety and security in the event of an accident. The compensation and compliance principles would require the US to pay for any damages incurred by the accident, so it is best to employ it over the ocean where any radioactive material will have the least impact to harming humans. While there are some who believe that no action that could cause such disaster should ever be employed, they are not in line with the international recognition of sovereign rights and that risks can be balanced against benefits gained.

Thus the question of whether the USAF should develop and operate a nuclear-powered is not one of military benefit or legal restrictions. Rather, it is one of political will. Without a doubt, the American public would not allow such technology to advance in today's circumstances. Resources are tight and the need is not immediate. Critics would quickly point to the failed ANP program and its cost and rekindle the fears from the Three Mile Island disaster. However, political will depends on many variables and changes over time. The USAF must be prepared and plan for future capabilities in a wide range of scenarios. The USAF should continue to understand the impacts nuclear-powered aircraft can have in various war game scenarios, using the concept of operations provided by this research, and to understand when the technology can be game changing and decisive. Furthermore, the USAF should continue to follow development of lightweight, deployable reactors intended to provide power to future air force bases. Such development could significantly advance development of nuclear-powered technology when the political environment changes and nuclear power is no longer a feared.

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